Diquark structures in hadron spectroscopy

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Diquark structures in hadron spectroscopy

Hot topic!! Signed by key names from all the world !!

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The diquark and some history

- The concept of a diquark is almost as old as the quark model, and actually predates QCD. M. Gell-Mann in his paper (Phys. Lett. 8, 214 (1964)) cites the possibility of diquarks; M. Ida and R. Kobayashi (Progr. Theor. Phys. 36, 846 (1966)) and D. B. Lichtenberg and L. J. Tassie Phys. Rev. 155, 1601 (1967) used that idea. After that many other authors!.

- QCD as a gauge theory provides additional motivation for diquarks, since perturbatively the short-distance forces between two quarks in the color-antitriplet configuration are half as attractive as those between a quark and antiquark in the color-singlet combination. Thus, quark (or antiquark) pairs are likely to bind together as colored quasiparticles and play a similar role to that of a single antiquark (quark) in building more complicated hadrons.

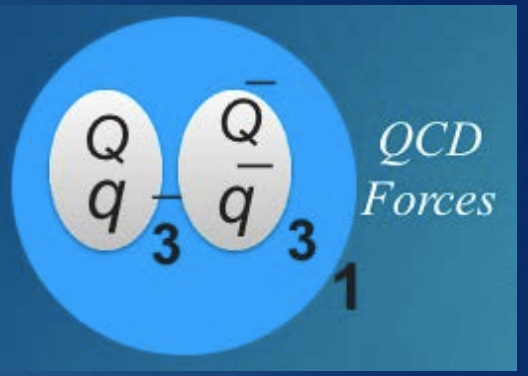
- This mechanism can manifest itself as diquark substructure in baryons, or be responsible for the emergence of compact tetra- and penta-quarks, in which all quarks are confined in the same volume and interact via direct color fields.

- **The diquark is an effective degree of freedom which describes two strongly correlated quarks**

Diquarks strongly motivated by QCD, but experimental evidence for them has been elusive, until recently

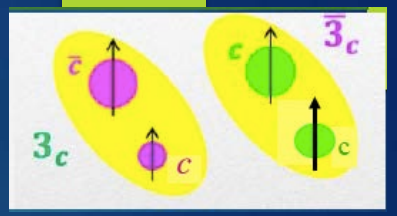
- The concept of diquark attraction is well grounded in QCD.
- Yet experimental evidence for diquarks has been at best elusive for many decades. Experimentally, we appear to be on the verge of a tipping point.
- In the next decade, experiments at hadron and lepton colliders are likely to provide much more unambiguous evidence for exotic hadrons and conventional baryons made out of diquarks.
- We propose to study experimental and theoretical directions of this now rapidly advancing research field! The two things are interconnected!

Mounting evidence for diquarks from the experiments on heavy-quark hadrons. Great prospects for more experimental results in the next decade and beyond.



- With the advent of many unexpected states with hidden charm such as X(3872), Zc(3900)± , and Zc(4020)± , Maiani et al. pointed out that these states can be interpreted as diquark-antidiquark compact tetraquarks.
- Note however that the proximity of these states to $D*\bar{D}$ (∗) thresholds also motivates molecular models, so these states could be diquark-based, molecule-based, or even a mixture of the two, but still same properties as prompt production or radiative decays can be explained only as compact states.
- Nevertheless, many other non-conventional states with hidden charm, like Zc(4430)± → ψ(2S)π±, or four X->J/psi phi, X(2900)->D+K- and X(6900)->J/psi J/psi do not fit such explanations
- whole family of states decaying to J/ψ φ, do not have simple molecular explanations, nor is it easy to accommodate all the non-conventional charmonium-like vector states as molecules

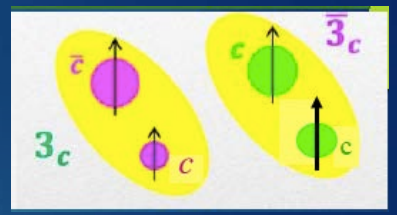
The best promises for a clear signature of tetraquarks made out of diquarks



- The very recent LHCb discovery of a significant mass structure near 6.9 GeV in J/ψ J/ψ invariant mass, the X(6900), offers perhaps the best promise for a clear signature of tetraquarks made out of diquarks, as there are no well-known mechanisms for attractive meson exchanges between two charmonium states
- Also very promising is the even more recent discovery by the LHCb of a relatively narrow scalar X(2900) state decaying to D+K−, which fits diquark-based tetraquark calculations for the ground state of a cs diquark plus a $\bar{u}\bar{d}$ antidiquark
- Diquar antidiquark models when applied to doubly-heavy diquarks, predict stable tetraquarks, especially using the bb diquark .

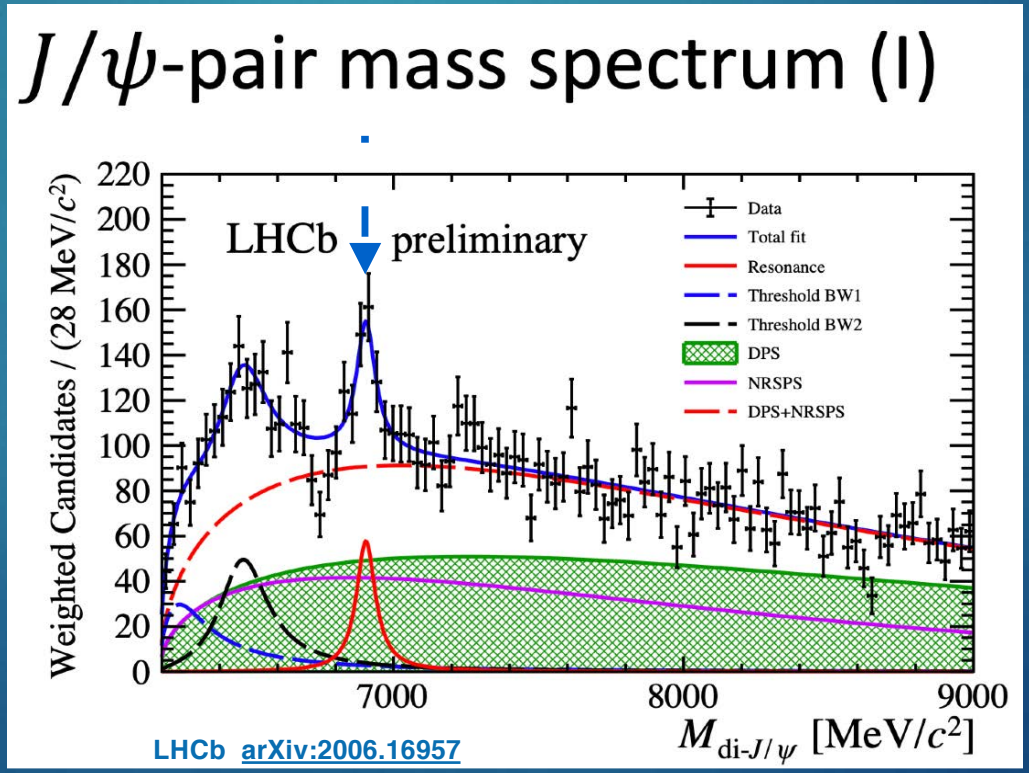
Tetraquark picture of 2 J/Ψ resonances

Describing the X(6900) structure with a Breit Wigner lineshape, its mass and natural width are determined to be (arXiv:2006.16957, 30 Jun 2020):

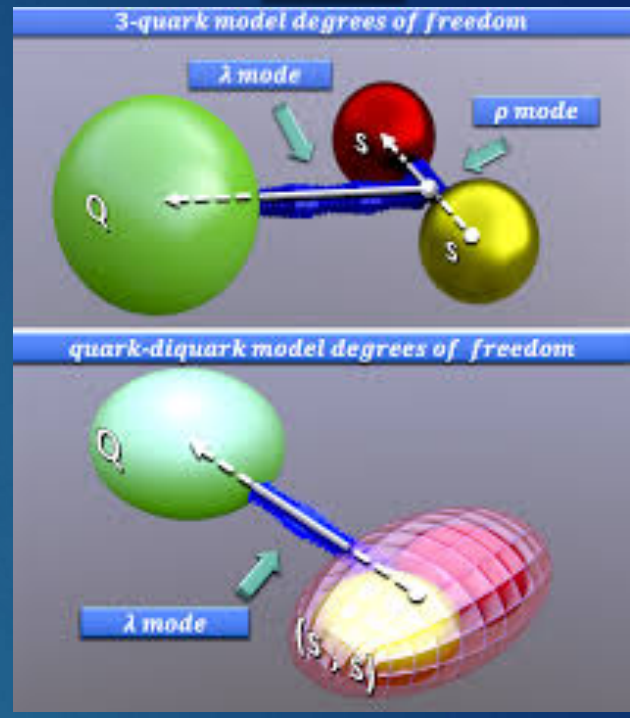


$$m[X(6900)] = 6905 \pm 11 \pm 7\,\text{MeV}/c^2$$

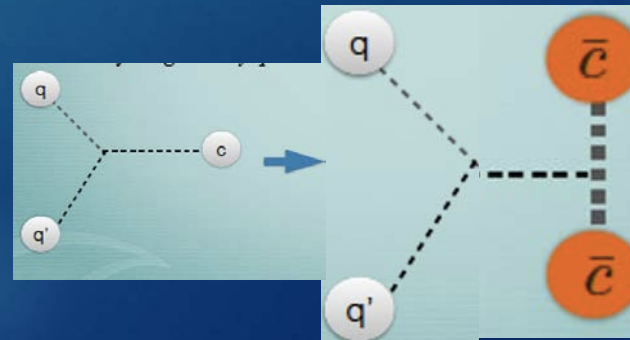
$$\Gamma[X(6900)] = 80 \pm 19 \pm 33\,\text{MeV},$$



Mounting evidence for diquarks from the experiments on heavy-quark hadrons. Great prospects for more experimental results in the next decade and beyond.



- The diquark models also share several features with the ones used for doubly-heavy baryons. The role of diquarks in conventional baryons is also a rich ground to be further explored. A clear signature of diquarks in Λ_b^0 was shown by LHCb in the lack of $\Lambda_b^0 \to J/\psi\Sigma^0$ events with respect to $\Lambda_b^0 \to J/\psi\Lambda$.
- With the upgrade of the LHCb and Belle-II experiments under way, and other programs such as ATLAS, CMS, BESIII, JLab, and eventually EIC and PANDA also contributing to conventional and exotic heavy-quark spectroscopy, the next decade promises to be very exciting.
- We propose to create a study group between theorists and experimentalists, to survey this dynamic field of research and identify the most promising avenues for more discoveries, obtain more data on the known diquark-based hadron candidates, and develop more advanced theoretical frameworks.



Needs to develop tools both from theoretical and experimental sides

- A lot of different phenomenological models of diquarks, not clear which ideas capture their properties properly. Need to develop them further using the experimental results and with help of lattice QCD.

- A lot of relatively narrow states discovered recently near heavy meson-meson and meson-baryon thresholds but also completely far from experimental thresholds . Likely to find more in the future.
- Their dynamic origin not clear.
- Proper data analysis is complicated. Need collaboration of experimentalists and theorists to clarify it.

- The rest is common between these LoIs: Experimental lois, Theoretical lois and LQCD and Analysis Lois.

We will work on between now and Snowmass and there is a schedule for developing a contributed paper

- A lot of support for these LoI from among theorists and experimentalists (~30 signatories from around the globe on each).
- Plan dedicated meetings to explore various aspects of related theory and review future experimental prospects (this has started already).
- Given the diverse community behind these LoI, we will need to develop a drafting strategy for related whitepaper (overall outline, name coordinators for specific sections).
- Schedule: in the next months (but see also below).

Common data sets, joint efforts, etc.

- Experimental prospects synergic with LoIs, and papers to be developed, by various experimental projects. Expect that experts from the experimental projects will participate in writing of both.
- These two LoIs (exp. and theor.) are synergic with each other.

Summing up
Outputs

- Recognition that some really fundamental questions on how hadronic structures are created are yet unanswered, and that ongoing and near-future experiments are likely to provide enough information to start answering them

- Call for funding for US participation in related experiments at home and abroad

- Call for funding for US theorists (phenomenologists and lattice QCD) to improve modelling of hadron structures

Contributed papers from various groups will make them more specific!

Thanks for your attention!